A CHROMATIC DISPERSION COMPENSATION MODULE

The field of the invention is that of chromatic dispersion compensation modules. The terms "attenuation" and "attenuation coefficient" are used interchangeably
5   with regard to optical fibers.

In some wavelength division multiplexing (WDM) optical fiber transmission networks including line optical fibers in which an optical signal propagates, there are no means of compensating the chromatic
10   dispersion of the line optical fibers. When the bit rate is low, for example 2.5 gigabits per second (Gbit/s) per channel, it is not necessary to compensate the chromatic dispersion of the line optical fibers. However, as the bit rate increases to high values, for example 10 Gbit/s
15   per channel, it becomes necessary to compensate the chromatic dispersion and the dispersion slope of the line optical fibers. A line optical fiber generally has positive chromatic dispersion and positive dispersion slope. Consequently, the optical fiber for compensating
20   chromatic dispersion will generally have negative chromatic dispersion and negative dispersion slope. The chromatic dispersion compensation optical fiber can be integrated into a chromatic dispersion compensation module. The spectral range within which chromatic
25   dispersion is to be compensated can include one or more of bands C, L and S.

The optical signal propagates in the chromatic dispersion compensation optical fiber. As it propagates in the chromatic dispersion compensation optical fiber,
30   the optical signal is liable to deteriorate, for example to suffer a decrease in the signal-to-noise ratio or an increase in non-linear effects. A chromatic dispersion compensation module for compensating the chromatic dispersion of a segment of line optical fiber, which is
35   usually several tens of kilometers (km) long, generally has insertion losses that are relatively high, of the order of several decibels (dB). Because of the magnitude

of its insertion losses, the chromatic dispersion
compensation module is generally placed at the center of
a two-stage amplifier system, i.e. between two
amplifiers.

5   For the two-stage amplifier system to have a good
optical signal-to-noise ratio and gain that is flat
across the spectrum, the two-stage amplifier system
presents a first amplifier with high gain, which yields
high optical power at the output of the first amplifier,
10   and presents losses between the two amplifiers at a level
that is fixed.

The chromatic dispersion compensation optical fiber
integrated into the chromatic dispersion compensation
module is a single-mode optical fiber which has a small
15   effective area, in the range 10 square micrometers (μm^2)
to 35 μm^2, which makes it very sensitive to non-linear
effects. To preserve good optical signal transmission
quality it is beneficial to limit the optical power input
into the chromatic dispersion compensation single-mode
20   optical fiber. To achieve this, an attenuator is placed
between the first amplifier and the chromatic dispersion
compensation module. The attenuator also controls the
flatness of the gain across the spectrum. The attenuator
can be replaced by a wavelength routing component or by
25   any other optical component that has losses and can
therefore, like the attenuator, limit the optical power
input into the chromatic dispersion compensation module.

The problem is to produce a chromatic dispersion
compensation module offering the best possible quality
30   whilst limiting its cost, i.e. achieving the best
possible quality-to-price ratio for the chromatic
dispersion compensation module. The question arises: how
are the quality, the cost, and the quality-to-price ratio
of a chromatic dispersion compensation module to be
35   evaluated?

It is known in the art to attempt to minimize the
insertion losses of the compensation module, and to this

end to increase as much a possible the figure of merit of the compensation optical fiber, which unfortunately greatly increases the cost of producing the compensation optical fiber and consequently the compensation module.
As the quality of the compensation module increases, the price increases at a faster rate, and the quality-to-price ratio is therefore degraded. The paper "Design optimization of dispersion compensating fiber for NZ-DSF considering nonlinearity and packaging performance" by T. Kato, M. Hirano, K. Fukuda, A. Tada, M. Onishi and M. Nishimura presented at the OFC 2001 conference, teaches attempting to minimize the non-linear phase of the compensation module, and to this end increasing as much as possible the figure of merit of the compensation optical fiber, which unfortunately greatly increases the cost of producing the compensation optical fiber and consequently the cost of the compensation module. As the quality of the compensation module increases, the price increases at a faster rate, and consequently the quality-to-price ratio is degraded.

Mediocre prior art compensation modules are available at reasonable cost and good prior art compensation modules are available at exorbitant cost. The object of the invention is to improve the quality-to-price ratio of a compensation module, and in particular to provide good modules at reasonable cost.

Prior art methods of improving the quality of a compensation module are based on unilaterally improving a parameter that is partially representative of the quality of the compensation module. Unilaterally improving only one parameter that is partially representative of the quality of the compensation module, whether that parameter be insertion losses or non-linear phase, has two consequences. Firstly, it increases the cost of the compensation module. Secondly, it tends to degrade the other parameter that is partially representative of the quality of the compensation module, which fails to

improve the quality of the compensation module, or improves it only slightly, or improves it insufficiently. Naturally, a very great increase in the figure of merit of the compensation optical fiber would always be
5   reflected in a greater or lesser improvement in the quality of the compensation module, but also in a very high increase in the cost of the compensation module, which is why the quality-to-price ratio of the compensation module is degraded.
10   The method of the invention of improving the quality of a compensation module is completely different. Firstly, it creates a quality criterion that is globally representative of the quality of a compensation module which integrates, with appropriate weighting, the
15   contribution of insertion losses and the contribution of non-linear effects. The contribution of insertion losses corresponds to the conventional insertion losses except that they are related to compensation over the entire line optical fiber, while the contribution of non-linear
20   effects is introduced by means of a non-linearity criterion that is related to the non-linear phase but is not the same as the non-linear phase. This non-linearity criterion is obtained by a clever simplification of the non-linear phase that takes account of the constant level
25   of losses between the two amplifiers of the two-stage amplifier system. This original quality criterion can be optimized with a chosen constant figure of merit of the compensation optical fiber, thereby improving the quality of the compensation module at constant cost, and thus
30   improving the quality-to-price ratio of the compensation module. To this end, in a manner that is entirely original and somewhat paradoxical, the invention is based on the observation that it is advantageous to increase the attenuation of the compensation optical fiber at a
35   constant figure of merit of the compensation optical fiber. With a constant figure of merit, the insertion losses remain exactly the same, while increasing

attenuation greatly improves the non-linearity criterion. The quality criterion suggests, even more paradoxically, that it can be beneficial to degrade slightly the figure of merit of the optical fiber, and consequently the

5 insertion losses, provided that the negative chromatic dispersion is made more negative and the figure of merit of the compensation optical fiber is reduced, which amounts to increasing the attenuation of the compensation optical fiber greatly, since this greatly improves the

10 non-linearity criterion, and thus more than adequately compensates for the degraded insertion losses. This is always advantageous, but especially so in the case of a two-stage amplifier system as referred to above, since in this case the slightly degraded insertion losses are not

15 reflected in any degradation of the optical signal, but only in reduced attenuation of the attenuator, and thus in a higher amplitude of the signal input into the compensation optical fiber, which the compensation optical fiber is well able to accept because its ability

20 to withstand non-linear effects has been significantly improved. The invention also creates a quality-to-price ratio criterion that integrates the extracost caused by improving the figure of merit of the compensation optical fiber, which makes it possible to verify that any

25 improvement in the figure of merit of the compensation optical fiber is reflected in a comparable improvement in the quality of the compensation module. To this end, provided that the improvement in the figure of merit is obtained much more by making the negative chromatic

30 dispersion of the compensation optical fiber more negative than it is by reducing the attenuation of the compensation optical fiber, and preferably when the improvement in the figure of merit is obtained by making the chromatic dispersion of the compensation optical

35 fiber more negative while simultaneously greatly increasing the attenuation of the compensation optical fiber, then this improvement in the figure of merit not

only improves quality, as expected, but also improves the quality-to-price ratio; in other words, it improves quality much more than it increases price.

Thus the invention proposes a compensation module design method and two compensation modules, one for compensating a standard single-mode line optical fiber (SMF) and the other for compensating a non-zero dispersion-shifted line optical fiber (NZ-DSF), i.e. a fiber in which the dispersion is shifted relative to the standard single-mode optical fiber and which has non-zero dispersion at the wavelength of 1550 nanometers (nm).

The invention provides a method of designing a chromatic dispersion compensation module,

said module being adapted to comprise,

an enclosure including an input terminal and an output terminal,

a chromatic dispersion compensation optical line situated inside the enclosure and connecting the input terminal to the output terminal, the line comprising one or more chromatic dispersion compensation single-mode optical fibers in series and not comprising any HOM multimode optical fiber,

said module being adapted to be inserted by means of the input and output terminals into a transmission line comprising a single-mode line optical fiber adapted to transmit information in a spectral domain of use,

the input terminal introducing into the transmission line an input loss Γ_{in} expressed in dB,

the output terminal introducing into the transmission line an output loss Γ_{out} expressed in dB,

additional connections, if any, between compensation optical fibers together introducing into the transmission line a connection loss Γ_{inter} expressed in dB,

the compensation optical fiber or the set of compensation optical fibers in series having, at a wavelength of 1550 nm, a plurality of average parameters including an average coefficient of attenuation α_{DCF}

expressed in decibels per kilometer (dB/km), a negative average chromatic dispersion D_{DCF} expressed in picoseconds per nanometer-kilometer (ps/nm-km), a negative average dispersion slope S_{DCF} expressed in picoseconds per

5   nanometersquared-kilometer (ps/nm²-km), an average chromatic dispersion to dispersion slope ratio D_{DCF}/S_{DCF} expressed in nm, an average figure of merit FOM_{DCF} defined as $-D_{DCF}/\alpha_{DCF}$ expressed in picoseconds per nanometer decibel (ps/nm-dB), an average effective area A_{eff}

10   expressed in μm^2, and an average second order coefficient n_2 of the refractive index as a function of the intensity expressed in 10^{-20} square meters per watt (m²/W),

the average chromatic dispersion to dispersion slope ratio being the ratio between the average chromatic

15   dispersion and the average dispersion slope,

the average figure of merit being the negative of the ratio between the average chromatic dispersion and the average coefficient of attenuation,

the average coefficient of attenuation in the case

20   of a single compensation optical fiber being lumped with the corresponding coefficient of attenuation of said single compensation optical fiber and in the case of a set of compensation optical fibers in series, the average coefficient of attenuation is equal to the sum of the

25   corresponding attenuation coefficients of the various compensation optical fibers weighted by their respective contributions to the total series length of the compensation optical fibers plus the ratio of the connection loss divided by said total length,

30   each of said other average parameters in the case of a single compensation optical fiber being lumped with the corresponding parameter of said single compensation optical fiber and each of said other average parameters in the case of a set of compensation optical fibers in

35   series being the arithmetic mean of the corresponding parameters of the various compensation optical fibers

when weighted by the respective lengths of said various compensation optical fibers,

said module being adapted to have insertion losses IL expressed in dB,

5   where $IL = \dfrac{D_{DCM}}{D_{DCF}} \cdot \alpha_{DCF} + \Gamma_{in} + \Gamma_{out}$

and where D_{DCM} represents the negative of the cumulative dispersion of the line optical fiber,

said module being adapted to have a non-linearity criterion NLC representing the effects of the non-linear

10   phase and expressed in 10^{-6}km/W-dB,

where $NLC = \dfrac{100 \cdot n_2 \cdot (1 - 10^{\frac{D_{DCM}}{10 \cdot FOM_{DCF}}})}{A_{eff} \cdot \alpha_{DCF} \cdot 10^{\frac{\Gamma_{in}}{10}}}$,

said module being adapted to have a quality criterion CQ expressed in dB,

where $CQ = IL + 10\log NLC$,

15   said design method including an optimization step for optimizing said module, said optimization step consisting in reducing the quality criterion at a chosen constant average figure of merit by increasing the average attenuation.

20   To compensate a standard single-mode line optical fiber, the invention also provides a chromatic dispersion compensation module comprising,

an enclosure including an input terminal and an output terminal,

25   a chromatic dispersion compensation optical line situated inside the enclosure and connecting the input terminal to the output terminal, the line comprising one or more chromatic dispersion compensation single-mode optical fibers in series and not comprising any HOM

30   multimode optical fiber,

the module being adapted to be inserted by means of the input and output terminals into a transmission line comprising a standard single-mode line optical fiber

adapted to transmit information in a spectral domain of use,

the input terminal introducing into the transmission line an input loss Γ_{in} expressed in dB,

5   the output terminal introducing into the transmission line an output loss Γ_{out} expressed in dB,

additional connections, if any, between compensation optical fibers together introducing into the transmission line a connection loss Γ_{inter} expressed in dB,

10   the compensation optical fiber or the set of compensation optical fibers in series having, at a wavelength of 1550 nm, a plurality of average parameters including an average coefficient of attenuation α_{DCF} expressed in dB/km, a negative average chromatic

15   dispersion D_{DCF} expressed in ps/nm-km, a negative average dispersion slope S_{DCF} expressed in ps/nm^2-km, an average chromatic dispersion to dispersion slope ratio D_{DCF}/S_{DCF} expressed in nm, an average figure of merit FOM_{DCF} defined as $-D_{DCF}/\alpha_{DCF}$ expressed in ps/nm-dB, an average effective

20   area A_{eff} expressed in μm^2, and an average second order coefficient n_2 of the refractive index as a function of the intensity expressed in $10^{-20}m^2/W$,

the average chromatic dispersion to dispersion slope ratio being the ratio between the average chromatic

25   dispersion and the average dispersion slope,

the average figure of merit being the negative of the ratio between the average chromatic dispersion and the average coefficient of attenuation,

the average coefficient of attenuation in the case

30   of a single compensation optical fiber being lumped with the corresponding coefficient of attenuation of said single compensation optical fiber and in the case of a set of compensation optical fibers in series, the average coefficient of attenuation is equal to the sum of the

35   corresponding attenuation coefficients of the various compensation optical fibers weighted by their respective contributions to the total series length of the

compensation optical fibers plus the ratio of the connection loss divided by said total length,

each of said other average parameters in the case of a single compensation optical fiber being lumped with the corresponding parameter of said single compensation optical fiber and each of said other average parameters in the case of a set of compensation optical fibers in series being the arithmetic mean of the corresponding parameters of the various compensation optical fibers when weighted by the respective lengths of said various compensation optical fibers,

the module having insertion losses IL expressed in dB,

where $IL = \dfrac{D_{DCM}}{D_{DCF}} \cdot \alpha_{DCF} + \Gamma_{in} + \Gamma_{out}$

and where $D_{DCM} = -1360$ ps/nm,

the module having a non-linearity criterion NLC representing the effects of the non-linear phase and expressed in 10^{-6}km/W-dB,

where $NLC = \dfrac{100 \cdot n_2 \cdot (1 - 10^{\frac{D_{DCM}}{10 \cdot FOM_{DCF}}})}{A_{eff} \cdot \alpha_{DCF} \cdot 10^{\frac{\Gamma_{in}}{10}}}$,

the module having a quality criterion CQ expressed in dB,

where $CQ = IL + 10\log NLC$,

the module having a quality-to-price ratio criterion CQ2 expressed in dB,

where $CQ2 = CQ + B\log(FOM_{DCF})$

and where B = 18,

and the compensation optical fiber or the set of compensation optical fibers in series having,

firstly, average chromatic dispersion more negative than -130 ps/nm-km,

secondly, average chromatic dispersion to dispersion slope ratio in the range 240 nm to 400 nm, and

thirdly, for a given average figure of merit, average attenuation sufficiently high for the quality

criterion to be less than 20.5 dB and the quality-to-price ratio criterion to be less than 61.3 dB.

To compensate a non-zero dispersion shifted single-mode line optical fiber, the invention further provides a chromatic dispersion compensation module comprising

an enclosure including an input terminal and an output terminal,

a chromatic dispersion compensation optical line situated inside the enclosure and connecting the input terminal to the output terminal, the line comprising one or more chromatic dispersion compensation single-mode optical fibers in series and not comprising any HOM multimode optical fiber,

the module being adapted to be inserted by means of the input and output terminals into a transmission line comprising a non-zero dispersion at 1550 nm single-mode dispersion shifted line optical fiber adapted to transmit information in a spectral domain of use,

the input terminal introducing into the transmission line an input loss Γ_{in} expressed in dB,

the output terminal introducing into the transmission line an output loss Γ_{out} expressed in dB,

additional connections, if any, between compensation optical fibers together introducing into the transmission line a connection loss Γ_{inter} expressed in dB,

the compensation optical fiber or the set of compensation optical fibers in series having, at a wavelength of 1550 nm, a plurality of average parameters including an average coefficient of attenuation α_{DCF} expressed in dB/km, a negative average chromatic dispersion D_{DCF} expressed in ps/nm-km, a negative average dispersion slope S_{DCF} expressed in ps/nm²-km, an average chromatic dispersion to dispersion slope ratio D_{DCF}/S_{DCF} expressed in nm, an average figure of merit FOM_{DCF} defined as $-D_{DCF}/\alpha_{DCF}$ expressed in ps/nm-dB, an average effective area A_{eff} expressed in μm^2, and an average second order

coefficient n_2 of the refractive index as a function of the intensity expressed in $10^{-20}m^2/W$,

the average chromatic dispersion to dispersion slope ratio being the ratio between the average chromatic

5   dispersion and the average dispersion slope, the average figure of merit being the negative of the ratio between the average chromatic dispersion and the average coefficient of attenuation,

the average coefficient of attenuation in the case

10   of a single compensation optical fiber being lumped with the corresponding coefficient of attenuation of said single compensation optical fiber and in the case of a set of compensation optical fibers in series, the average coefficient of attenuation is equal to the sum of the

15   corresponding attenuation coefficients of the various compensation optical fibers weighted by their respective contributions to the total series length of the compensation optical fibers plus the ratio of the connection loss divided by said total length,

20   each of said other average parameters in the case of a single compensation optical fiber being lumped with the corresponding parameter of said single compensation optical fiber and each of said other average parameters in the case of a set of compensation optical fibers in

25   series being the arithmetic mean of the corresponding parameters of the various compensation optical fibers when weighted by the respective lengths of said various compensation optical fibers,

the module having insertion losses IL expressed in

30   dB,

where $IL = \dfrac{D_{DCM}}{D_{DCF}} \cdot \alpha_{DCF} + \Gamma_{in} + \Gamma_{out}$

and where D_{DCM} = -680 ps/nm,

the module having a non-linearity criterion NLC representing the effects of the non-linear phase and

35   expressed in 10^{-6} kilometers per watt-decibel (km/W-dB),

where $NLC = \dfrac{100 \cdot n_2 \cdot (1 - 10^{\frac{D_{DCM}}{10 \cdot FOM_{DCF}}})}{A_{eff} \cdot \alpha_{DCF} \cdot 10^{\frac{\Gamma_{in}}{10}}}$,

the module having a quality criterion CQ expressed in dB,

where $CQ = IL + 10 \log NLC$,

5   the module having a quality-to-price ratio criterion CQ2 expressed in dB,

where $CQ2 = CQ + B \log(FOM_{DCF})$

and where B = 23,

and the compensation optical fiber or the set of

10   compensation optical fibers in series having,

firstly, an average chromatic dispersion more negative than -115 ps/nm-km, and

secondly, for a given average figure of merit, average attenuation sufficiently high for the quality

15   criterion to be less than 18 dB and the quality-to-price ratio criterion to be less than 66.6 dB.

Although less pertinent in the context of use with an amplification and compensation system other than the two-stage amplification and compensation system referred

20   to above, the quality and quality-to-price ratio criteria remain valid and beneficial. The invention is not limited to use in the context of a two-stage amplification and compensation system of the type described hereinabove.

25   The invention will be more clearly understood and other features and advantages will become apparent in the light of the following description and the accompanying drawings, which are provided by way of example, and in which:

30   - Figure 1 is a diagram showing an example of a transmission line integrating a compensation module of the invention;

- Figure 2 is a diagram showing an example of a compensation module of the invention;

35   - Figure 3 is a table comparing the relative

performance of prior art compensation modules and examples of compensation modules of the invention in the case of compensating a standard single-mode line optical fiber;

5   - Figure 4 is a table comparing the relative performance of prior art compensation modules and examples of compensation modules of the invention in the case of compensating a non-zero dispersion shifted single-mode line optical fiber;

10   - Figure 5 is a diagram showing a family of curves plotting the variation in the quality criterion as a function of the figure of merit for the compensation optical fiber at a chosen constant chromatic dispersion for the compensation optical fiber in the case of

15   compensating a standard single-mode line optical fiber;

- Figure 6 is a diagram showing a family of curves plotting the variation in the quality-to-price ratio criterion as a function of the figure of merit of the compensation optical fiber at a chosen constant chromatic

20   dispersion for the compensation optical fiber in the case of compensating a standard single-mode line optical fiber;

- Figure 7 is a diagram showing a family of curves plotting the variation in the quality criterion as a

25   function of the figure of merit of the compensation optical fiber at a chosen constant attenuation for the compensation optical fiber in the case of compensating a standard single-mode line optical fiber;

- Figure 8 is a diagram showing a family of curves

30   plotting the variation in the quality-to-price ratio criterion as a function of the figure of merit of the compensation optical fiber at a chosen constant attenuation for the compensation optical fiber in the case of compensating a standard single-mode line optical

35   fiber;

- Figure 9 is a diagram showing a family of curves plotting the variation in the quality criterion as a

function of the chromatic dispersion of the compensation optical fiber at a chosen constant figure of merit for the compensation optical fiber in the case of compensating a standard single-mode line optical fiber;

5   and

- Figure 10 is a diagram showing a. family of curves plotting the variation in the quality criterion as a function of the attenuation of the compensation optical fiber at a chosen constant figure of merit for the

10   compensation optical fiber in the case of compensating a standard single-mode line optical fiber.

All of Figures 5 to 10 relate to compensating a standard single-mode line optical fiber, but the trends of the curves are the same when compensating a non-zero

15   dispersion shifted single-mode line optical fiber. Parameters and criteria that are used throughout the remainder of the text are defined next. There are two situations to consider: either the module comprises a single compensation optical fiber, which fiber has

20   parameters, or the module comprises a plurality of compensation optical fibers in series, constituting a set of fibers which has average parameters. For simplicity, in all of Figures 1 to 10 the compensation module is considered as comprising only one compensation optical

25   fiber and the qualifier "average" in the definition of the parameters may be disregarded.

When the compensation module comprises only one compensation optical fiber, the module has the great advantage that its design and fabrication are simplified.

30   When the compensation module comprises a plurality of compensation optical fibers from the same family, i.e. either a plurality of segments taken from one and the same compensation optical fiber or from different production runs of the same compensation optical fiber,

35   and therefore subject to slight differences caused by fabrication tolerances, and the optical fibers are matched and assembled together, the fibers provide some

properties that are defined with great accuracy, despite wider fabrication tolerances, for example more accurate compensation of the dispersion slope or the chromatic dispersion to dispersion slope ratio of the line optical

5   fiber. The compensation optical fibers of the same family are preferably connected together directly, but could be connected together by means of a connector. The compensation module has the advantages of simplicity of design and of improvement of some of its properties.

10   When the compensation module comprises a plurality of separate compensation optical fibers that are matched and assembled together, they provide compensation over a very wide spectral band, i.e. over at least two of the spectral bands S, C and L. The S, C and L spectral bands

15   respectively range from approximately 1460 nanometers (nm) to approximately 1530 nm, from approximately 1530 nm to approximately 1565 nm, and from approximately 1565 nm to approximately 1615 nm. However, the compensation module then has the drawback that its design and

20   production are difficult.

Consider two fibers having respective lengths $\ell 1$ and $\ell 2$, respective coefficients of attenuation per unit length a1 and a2, and a connection loss pc between the two fibers. The average coefficient of attenuation per

25   unit length am of all of the compensation optical fibers in series has the value am = (a1.$\ell 1$ + a2.$\ell 2$ + pc)/($\ell 1$ + $\ell 2$). This type of calculation of the average attenuation coefficient can be generalized to more than two compensation optical fibers in series. Only the average

30   coefficient of attenuation, which is a special case of the optical fiber parameters, is calculated in this manner, and all the other average parameters are calculated in other ways.

Consider two optical fibers with respective lengths

35    $\ell 1$ and $\ell 2$ and respective chromatic dispersions per unit length c1 and c2. The average chromatic dispersion per unit length cm of all of the compensation optical fibers

in series has the value cm = (c1.ℓ1 + c2.ℓ2)/(ℓ1 + ℓ2).
This type of average chromatic dispersion calculation can
be generalized to more than two compensation optical
fibers in series. All the other average parameters, with
5   the exception of the average coefficient of attenuation,
the average chromatic dispersion to dispersion slope
ratio, and the average figure of merit, are calculated in
this manner, namely, the average dispersion slope, the
average effective area, and the average second order
10 coefficient, conventionally designated n_2, of the
refractive index of the optical fiber as a function of
the intensity of the optical signal propagating in the
optical fiber. The average chromatic dispersion to
dispersion slope ratio is the ratio between the average
15 chromatic dispersion and the average dispersion slope.
The average figure of merit is the negative of the ratio
between the average chromatic dispersion and the average
coefficient of attenuation.

   There is an exact non-linearity criterion formula in
20 the case of two compensation optical fibers in series,
referred to as optical fiber a and optical fiber b, for
example. The exponents a and b of the various parameters
represent those parameters for the optical fibers a and
b, respectively.

25   The exact formula, in which $\Gamma_{in}^{b} = \Gamma_{inter}$ in the case of
two compensation optical fibers in series, is as follows
:

$$NLC = 100 \cdot \left(\frac{n_2^a}{A_{eff}^a \cdot \alpha_{DCF}^a \cdot 10^{\left(\frac{\Gamma_{in}^a}{10}\right)}} [1 - 10^{\left(\frac{D_{DCM}^a}{10 \cdot FOM_{DCF}^a}\right)}] + \frac{10^{\left(\frac{D_{DCM}^a \cdot \alpha_{DCF}^b}{10 \cdot FOM_{DCF}^a \cdot \alpha_{DCF}^a}\right)} \cdot n_2^b}{A_{eff}^b \cdot \alpha_{DCF}^b \cdot 10^{\left(\frac{\Gamma_{in}^a + \Gamma_{in}^b}{10}\right)}} [1 - 10^{\left(\frac{D_{DCM}^b}{10 \cdot FOM_{DCF}^b}\right)}] \right)$$

   However, approximate formulas obtained from the
30 average parameters of the compensation optical line yield
excellent results that are very similar to those obtained
using the exact formula. This is why the approximate
formula is used.

   The chromatic dispersion compensation module
35 comprises a chromatic dispersion compensation optical

line and an enclosure having an input terminal and an
output terminal. The chromatic dispersion compensation
line comprises one chromatic dispersion compensation
single-mode optical fiber or two chromatic dispersion
5   compensation single-mode optical fibers in series, does
not comprise any HOM multimode optical fiber, is situated
in the enclosure, and connects the input terminal to the
output terminal. The module is intended to be connected,
by means of the input and output terminals, into a
10   transmission line comprising a single-mode line optical
fiber adapted to transmit information in a spectral
domain of use. The input terminal introduces into the
transmission line an input loss Γ_{in} expressed in dB. The
output terminal introduces into the transmission line an
15   output loss Γ_{out} expressed in dB. If the compensation
line comprises a plurality of compensation optical fibers
in series, additional connections between compensation
optical fibers together introduce into the transmission
line a connection loss Γ_{inter} expressed in dB.
20   The compensation optical fiber, or the set of
compensation optical fibers in series, has average
parameters at a wavelength of 1550 nm including an
average coefficient of attenuation α_{DCF} expressed in
dB/km, an average chromatic dispersion D_{DCF} expressed in
25   ps/nm-km and that is negative, an average dispersion
slope S_{DCF} expressed in ps/nm^2-km and that is negative, an
average chromatic dispersion to dispersion slope ratio
D_{DCF}/S_{DCF} expressed in nm, an average figure of merit FOM_{DCF}
expressed in ps/nm-dB and equal to $-D_{DCF}/\alpha_{DCF}$ (giving a
30   positive value since D_{DCF} is itself negative), an average
effective area A_{eff} expressed in μm^2, and an average second
order refractive index coefficient as a function of
intensity n_2 expressed in $10^{-20}m^2/W$. As already explained
above, firstly, the average coefficient of attenuation in
35   the case of a single compensation optical fiber is lumped
with the corresponding coefficient of attenuation of the
single compensation optical fiber and in the case of a

set of compensation optical fibers in series, the average
coefficient of attenuation is equal to the sum of the
corresponding attenuation coefficients of the various
compensation optical fibers weighted by their respective
5   contributions to the total series length of the
compensation optical fibers plus the ratio of the
connection loss divided by said total length, and
secondly each of the other average parameters in the case
of a single compensation optical fiber is lumped with the
10   corresponding parameter of the single compensation
optical fiber and each of the other average parameters in
the case of a set of compensation optical fibers in
series is equal to the arithmetic mean of the
corresponding parameters of the compensation optical
15   fibers when weighted by the respective lengths of the
compensation optical fibers.

The module has insertion losses IL,

where $IL = \dfrac{D_{DCM}}{D_{DCF}} \cdot \alpha_{DCF} + \Gamma_{in} + \Gamma_{out}$ and

where D_{DCM} = -1360 ps/nm for compensating a standard
20   single-mode line optical fiber or D_{DCM} = -680 ps/nm for
compensating one example of a non-zero dispersion shifted
single-mode line optical fiber. A standard segment of
single-mode line optical fiber is approximately 80
kilometers (km) long, which gives an approximate
25   cumulative chromatic dispersion of -1360 ps/nm for a
standard single-mode line optical fiber or approximately
-680 ps/nm for such an example of a non-zero dispersion
shifted single-mode line optical fiber. Even for other
examples of non-zero dispersion shifted single-mode line
30   optical fiber having a cumulative dispersion slightly
different from -680 ps/nm, evaluating the quality
criterion with D_{DCM} = -680 ps/nm remains entirely valid.
Moreover, to evaluate the quality of a module, the
insertion losses are not the real insertion losses of the
35   module, which could be relatively low if the module
compensates only a portion of the cumulative dispersion,

but rather the insertion losses that the module would have if it fully compensated the cumulative dispersion with a length of compensation optical fiber slightly longer than the length required to compensate only part

5   of the cumulative dispersion. Moreover, in the formulae for the quality criterion, the quality-to-price ratio criterion, and the non-linearity criterion, the cumulative dispersion is chosen to be -1360 ps/nm or -680 ps/nm depending on the type of single-mode line

10 optical fiber to be compensated, but the module can also be used to compensate other values of cumulative dispersion or even to compensate only a portion of the cumulative dispersion. The insertion losses decrease as the figure of merit increases. The insertion losses

15 remain constant for a constant figure of merit.

         To be able to compensate to within approximately ±20% the chromatic dispersion to dispersion slope ratio of a standard single-mode line optical fiber, the compensation optical fiber or the set of compensation

20 optical fibers in series has an average chromatic dispersion to dispersion slope ratio in the range 240 nm to 400 nm. To be able to compensate to within approximately ±10% the chromatic dispersion to dispersion slope ratio of a standard single-mode line optical fiber,

25 the compensation optical fiber or the set of compensation optical fibers in series preferably has an average chromatic dispersion to dispersion slope ratio in the range 270 nm to 370 nm.

         To be able to compensate the chromatic dispersion to

30 dispersion slope ratio of most non-zero dispersion shifted single-mode line optical fibers, the compensation optical fiber or the set of compensation optical fibers in series preferably has an average chromatic dispersion to dispersion slope ratio less than 200 nm.

35   The module has a non-linearity criterion (NLC) representing non-linear effects, i.e. the effects of non-linear phase, in the particular case of constant losses

between the two amplifiers of the two-stage amplifier system,

where $NLC = \dfrac{100 \cdot n_2 \cdot (1 - 10^{\frac{D_{DCM}}{10 \cdot FOM_{DCF}}})}{A_{eff} \cdot \alpha_{DCF} \cdot 10^{\frac{\Gamma_{in}}{10}}}$.

5   However, although less relevant in other amplification system structures, such as a single-stage amplifier system comprising only one amplifier and no attenuator, the non-linearity criterion would then continue to be of benefit anyway. This non-linearity criterion leads to a seeming paradox, namely that

10   increasing the attenuation of an optical fiber at constant figure of merit reduces the non-linearity criterion and increases the performance of the module. The non-linearity criterion can even be reduced by reducing the figure of merit, provided that the

15   attenuation is increased sufficiently without excessively degrading the effective area and the coefficient n_2.

The module has a quality criterion CQ defined as follows: *CQ = IL + 10logNLC*. The two contributions, namely the insertion losses and the non-linearity

20   criterion, are reduced to the same units and expressed in dB. The quality criterion CQ is representative of the overall quality of a compensation module.

The module has a quality-to-price ratio criterion CQ2 that is defined as follows: *CQ2 = CQ + Blog(FOM_{DCF})*,

25   where B = 18 for compensating a standard single-mode line optical fiber or B = 23 for compensation of a non-zero dispersion shifted single-mode line optical fiber. The figure of merit of a compensation optical fiber is representative of the difficulty of producing the

30   compensation optical fiber and consequently the cost of the associated compensation module, and high figures of merit are even more difficult to obtain when seeking to achieve chromatic dispersion to dispersion slope ratios close to those of non-zero dispersion shifted single-mode

35   line optical fibers than when seeking to achieve

chromatic dispersion to dispersion slope ratios close to the highest ratios that can be achieved for standard single-mode line optical fibers. This explains the difference in the value of the coefficient B, which is

5   increased in the range 18 to 23 to take account of this greater difficulty in production. The portion $Blog(FOM_{DCF})$ is also expressed in dB.

Especially when integrating the compensation module into the middle of a two-stage amplifier system, the

10   quality criterion indicates that it is beneficial to degrade the insertion losses slightly if the losses due to the non-linear effects represented by the non-linearity criterion are improved proportionately more. For example, it is beneficial to increase the insertion

15   losses by 1 dB if this decreases the contribution of the non-linearity criterion to the quality criterion by 2 dB. Since the insertion losses between the two amplifiers of the two-stage amplification system are fixed, any reduction of the insertion losses below the fixed

20   threshold has no benefit except for the resulting reduction in non-linear effects, which can be obtained more easily by greatly reducing the quality criterion in conjunction with a small increase in the insertion losses. Below the fixed threshold, additional reduction

25   of the insertion losses will not achieve any improvement in terms of the overall optical loss budget, because it will be canceled out by a corresponding increase in the attenuation of the attenuator; the only advantage associated with this reduction of the insertion losses is

30   achieved in terms of ability to accommodate non-linear effects, which improved ability can be obtained more easily and more effectively by trading a slight increase in the insertion losses against a correspondingly greater reduction of the non-linearity criterion. The largest

35   contribution to the quality criterion is that of the non-linearity criterion; consequently, it is beneficial to rebalance the respective contributions of the insertion

losses and the non-linearity criterion with the aid of a loss distribution criterion CRP, which is defined as follows:

$$CRP = 1 - \frac{2IL}{CQ} \, ,$$

5   which is equivalent to $CRP = \dfrac{10 \log NLC - IL}{10 \log NLC + IL} \, ,$

and this must be reduced.

With a chosen constant figure of merit for the compensation optical fiber, reducing the quality criterion amounts to reducing the non-linearity

10 criterion, since the insertion losses are constant for a constant figure of merit of the compensation optical fiber when the only parameters that vary are the parameters of the compensation optical fiber. Reducing the non-linearity criterion at constant figure of merit

15 amounts to increasing the product of multiplying the attenuation by the effective area and dividing by the coefficient n_2. Reducing n_2 and increasing the effective area seem only natural, whereas increasing the attenuation of the compensation optical fiber seems

20 somewhat paradoxical. The invention reflects this in an increase in the module optimization criterion COM, which is expressed in 10^{10} dB^2 -W/s, is defined as follows:

$$COM = \frac{100 \cdot \alpha_{DCF} \cdot A_{eff}}{n_2 \cdot FOM_{DCF}} \, ,$$

and this is to be increased. Somewhat surprisingly,

25 although in the prior art the aim has been to minimize the attenuation of the compensation optical fiber whatever the cost, this attenuation is located in the numerator of a fraction that is to be increased, and although in the prior art the aim has been to increase

30 the figure of merit of the compensation optical fiber whatever the cost, this figure of merit is located in the denominator of a fraction that is to be increased. A relatively high module optimization criterion corresponds to a compensation optical fiber that is optimized for use

in a compensation module.

Figure 1 is a diagram showing an example of a transmission line integrating a compensation module of the invention. The transmission line corresponds to a

5   segment which, when periodically repeated and combined with send and receive devices, constitutes the communications system. The transmission line comprises in succession, in the propagation direction of the optical signal, a line optical fiber 1 and an

10   amplification and compensation system 6. The amplification and compensation system 6 comprises in succession an upstream amplifier 2, an attenuator 3, a compensation module 4 of the invention, and a downstream amplifier 5. Downstream from the downstream amplifier 5

15   is the line optical fiber 1 of the next segment. After propagating along the line optical fiber 1, the optical signal is amplified by the upstream amplifier 2, attenuated by the attenuator 3, has its chromatic dispersion compensated by the compensation module 4, and

20   is amplified again by the downstream amplifier 5, before entering the next segment, i.e. the next transmission line.

Figure 2 is a diagram showing an example of a compensation module of the invention. The compensation

25   module 4 comprises an enclosure 49 containing, in succession: an input terminal 41; a chromatic dispersion compensation optical line 40; and an output terminal 42. The compensation optical line 40 can comprise one or more optical fibers in series interconnected by connectors.

30   In Figure 2, for example, the compensation optical line 40 comprises two compensation optical fibers 43 and 45 connected together by a connector 44. On the upstream side, at the output of the attenuator 3, the optical signal enters via the input terminal 41, propagates in

35   the compensation optical fiber 43, passes through the connector 44, propagates in the compensation optical fiber 45, and then exits via the downstream output

terminal 42, i.e. at the input of the downstream amplifier 5.

Figure 3 is a table comparing the relative performance of prior art compensation modules and examples of compensation modules in accordance with the invention in the case of compensating a standard single-mode line optical fiber. The first column gives the numbers of the compensation module examples. The prior art compensation module examples are numbered A1, A2, B1, B2, C1, C2. The examples of compensation modules in accordance with the invention are numbered N1, N2, N3, N4. The next column gives the negative of the cumulative chromatic dispersion of the line optical fiber, which is the negative of the chromatic dispersion that it would be necessary to compensate in order to compensate fully 80 km of the line optical fiber. This parameter is denoted D_{DCM} and is expressed in ps/nm. The next column gives the chromatic dispersion of the compensation optical fiber, denoted D_{DCF} and expressed in ps/nm-km. The next column gives the dispersion slope of the compensation optical fiber, which is denoted S_{DCF} and is expressed in ps/nm^2-km. The next column gives the average chromatic dispersion to dispersion slope ratio of the compensation optical fiber, which is denoted D_{DCF}/S_{DCF} and is expressed in nm. The next column gives the coefficient of attenuation of the compensation optical fiber, which is denoted α_{DCF} and is expressed in dB/km. The next column gives the figure of merit of the compensation optical fiber, which is denoted FOM_{DCF} and is expressed in ps/nm-dB. The next column gives the input loss of the input terminal of the compensation module, which is substantially equal to the output loss of the output terminal of the compensation module, is denoted Γ and is expressed in dB. The next column gives the insertion losses of the compensation module, which are denoted IL and are expressed in dB. The next column gives the effective area of the compensation fiber, which

is denoted A_{eff} and is expressed in μm^2. The next column
gives the average second order coefficient of the
refractive index of the compensation optical fiber as a
function of the intensity of the light signal that
5 propagates in the fiber, which is denoted n_2 and is
expressed in 10^{-20} m^2/W. The next column gives the non-
linearity criterion of the compensation module, which is
denoted NLC and is expressed in 10^{-6} km/W-dB. The next
column gives the quality criterion of the compensation
10 module, which is denoted CQ and is expressed in dB. The
next column gives the quality-to-price ratio criterion of
the compensation module, which is denoted CQ2 and is
expressed in dB. The next column gives the module
optimization criterion of the compensation optical fiber,
15 which is denoted COM and is expressed in 10^{-10} dB^2-W/s.
The next column gives the loss distribution criterion of
the compensation module, which is denoted CRP and is
expressed in %.

Compensation modules of the invention have a
20 quality-to-price ratio criterion which is much lower and
therefore significantly better than that of prior art
modules: there is more than half a decibel difference
between the worst compensation module obtained by means
of the method of the invention and the best prior art
25 compensation module. An improvement of half a decibel is
already considerable.

The invention preferably relates to compensation
modules having a very good quality criterion; to this
end, the compensation optical fiber or the set of
30 compensation optical fibers in series has, for a given
average figure of merit, an average attenuation that is
sufficiently high for the quality criterion to be less
than 18.5 dB.

The invention preferably relates to compensation
35 modules having an excellent quality criterion; to this
end, the compensation optical fiber or the set of
compensation optical fibers in series has, for a given

average figure of merit, an average attenuation that is sufficiently high for the quality criterion to be less than 17.5 dB.

The invention preferably relates to compensation modules having a very good quality-to-price ratio criterion; to this end, the compensation optical fiber or the set of compensation optical fibers in series has, for a given average figure of merit, an average attenuation that is sufficiently high for the quality criterion to be less than 60.8 dB.

The invention preferably relates to compensation modules having an excellent quality-to-price ratio criterion; to this end, the compensation optical fiber or the set of compensation optical fibers in series has, for a given average figure of merit, an average attenuation that is sufficiently high for the quality criterion to be less than 60.3 dB.

Still with the aim of improving the quality criterion or the quality-to-price ratio criterion, the compensation module preferably complies with a number of preferred thresholds described below.

The compensation optical fiber or the set of compensation optical fibers in series preferably has a module optimization criterion that is greater than 2. The module optimization criterion is advantageously greater than 2.5.

The compensation optical fiber or the set of compensation optical fibers in series preferably has an average figure of merit in the range 200 ps/nm-dB to 250 ps/nm-dB.

The compensation optical fiber or the set of compensation optical fibers in series preferably has an average attenuation greater than 0.9 dB/km. The compensation optical fiber or the set of compensation optical fibers in series advantageously has an average attenuation greater than 1.1 dB/km.

The compensation module preferably has a loss

distribution criterion that is less than 30%. The loss distribution criterion is advantageously less than 23%.

Figure 4 is a table comparing the relative performance of prior art compensation modules and examples of compensation modules in accordance with the invention in the case of compensating a non-zero dispersion shifted single-mode line optical fiber. The first column gives the numbers of the compensation module examples. The prior art compensation module examples are numbered B1, B2, B3, B4, C1, C2, C3, C4, C5, C6, C7. The examples of compensation modules in accordance with the invention are numbered N1, N2, N3, N4, N5. This numbering of the modules is not related in any way to the numbering of the modules used in Figure 3: the same numbers in Figures 3 and 4 correspond to modules that are totally unrelated. The next column gives the negative of the cumulative chromatic dispersion of the line optical fiber, which is the negative of the chromatic dispersion that it would be necessary to compensate in order to fully compensate 80 km of the line optical fiber. This parameter is denoted D_{DCM} and is expressed in ps/nm. The cumulative chromatic dispersion of a non-zero dispersion shifted single-mode line optical fiber is lower than the cumulative chromatic dispersion of a standard single-mode line fiber because its chromatic dispersion is lower. The next column gives the chromatic dispersion of the compensation optical fiber, which is denoted D_{DCF} and expressed in ps/nm-km. The next column gives the dispersion slope of the compensation optical fiber, which is denoted S_{DCF} and is expressed in ps/nm^2-km. The next column gives the average chromatic dispersion to dispersion slope ratio of the compensation optical fiber, which is denoted D_{DCF}/S_{DCF} and is expressed in nm. The next column gives the coefficient of attenuation of the compensation optical fiber, which is denoted α_{DCF} and is expressed in dB/km. The next column gives the figure of merit of the compensation optical fiber, which is denoted

FOM_{DCF} and is expressed in ps/nm-dB. The next column gives the input loss at the input terminal of the compensation module, which is substantially equal to the output loss at the output terminal of the compensation module, is denoted Γ and is expressed in dB. The next column gives the insertion losses of the compensation module, which are denoted IL and are expressed in dB. The next column gives the effective area of the compensation fiber, which is denoted A_{eff} and is expressed in μm^2. The next column gives the average second order coefficient of the refractive index of the compensation optical fiber as a function of the intensity of the light signal that propagates in the fiber, which is denoted n_2 and is expressed in 10^{-20} m^2/W. The next column gives the non-linearity criterion of the compensation module, which is denoted NLC and is expressed in 10^{-6} km/W-dB. The next column gives the quality criterion of the compensation module, which is denoted CQ and is expressed in dB. The next column gives the quality-to-price ratio criterion of the compensation module, which is denoted CQ2 and is expressed in dB. The next column gives the module optimization criterion of the compensation optical fiber, which is denoted COM and is expressed in 10^{-10} dB^2-W/s. The next column gives the loss distribution criterion of the compensation module, which is denoted CRP and is expressed in %.

The compensation modules of the invention have a quality-to-price ratio criterion which is much lower and therefore much better than that of the prior art modules: there is more than one decibel difference between the worst compensation module obtained by the method of the invention and the best prior art compensation module. A gain of one decibel is already considerable.

The invention preferably relates to compensation modules having a very good quality criterion; to this end, the compensation optical fiber or the set of compensation optical fibers in series has, for a given

average figure of merit, an average attenuation that is sufficiently high for the quality criterion to be less than 15 dB.

The invention preferably relates to compensation modules having an excellent quality criterion; to this end, the compensation optical fiber or the set of compensation optical fibers in series has, for a given average figure of merit, an average attenuation that is sufficiently high for the quality criterion to be less than 13 dB.

The invention preferably relates to compensation modules having a very good quality-to-price ratio criterion; to this end, the compensation optical fiber or the set of compensation optical fibers in series has, for a given average figure of merit, an average attenuation that is sufficiently high for the quality-to-price ratio criterion to be less than 66.1 dB.

The invention preferably relates to compensation modules having an excellent quality-to-price ratio criterion; to this end, the compensation optical fiber or the set of compensation optical fibers in series has, for a given average figure of merit, an average attenuation that is sufficiently high for the quality-to-price ratio criterion to be less than 65.6 dB.

Still with the aim of improving the quality criterion or the quality-to-price ratio criterion, the compensation module preferably complies with a number of preferred thresholds described below.

The compensation optical fiber or the set of compensation optical fibers in series preferably has a module optimization criterion that is greater than 3. The module optimization criterion is advantageously greater than 4.

The compensation optical fiber or the set of compensation optical fibers in series preferably has an average figure of merit in the range 170 ps/nm-dB to 220 ps/nm-dB.

The compensation optical fiber or the set of
compensation optical fibers in series preferably has an
average attenuation greater than 1.1 dB/km. The
compensation optical fiber or the set of compensation
5   optical fibers in series advantageously has an average
attenuation greater than 1.3 dB/km.

The compensation optical module preferably has a
loss distribution criterion less than 35%. The loss
distribution criterion is advantageously less than 28%.
10   Figure 5 is a diagram showing a family of curves
plotting the variation in the quality criterion as a
function of the figure of merit of the compensation
optical fiber at a chosen constant chromatic dispersion
for the compensation optical fiber and in the case of
15   compensating a standard single-mode line optical fiber.
The quality criterion CQ expressed in dB is plotted up
the ordinate axis. The figure of merit FOM_{DCF} expressed
in ps/nm-dB is plotted along the abscissa axis. Curve CA
corresponds to a chromatic dispersion of -150 ps/nm-km.
20   Curve CB corresponds to a chromatic dispersion of
-200 ps/nm-km. Curve CC corresponds to a chromatic
dispersion of -250 ps/nm-km. By their relatively shallow
slope and their relatively large spacing, the curves CA,
CB, CC show that to in order to reduce the quality
25   criterion, and thus to improve it, it is more effective
to reduce the chromatic dispersion of the compensation
optical fiber at constant figure of merit than it is to
increase the figure of merit of the compensation optical
fiber at constant chromatic dispersion. This is
30   particularly true if the figure of merit is high and in
particular greater than a value of approximately
200 ps/nm-dB. When compensating a non-zero dispersion
shifted line optical fiber, the value of that preferred
threshold is around 150 ps/nm-dB.
35   Figure 6 is a diagram showing a family of curves
plotting the variation in the quality-to-price ratio
criterion as a function of the figure of merit of the

compensation optical fiber at a chosen constant chromatic dispersion for the compensation optical fiber and in the case of compensating a standard single-mode line optical fiber. The quality-to-price ratio criterion CQ2

5   expressed in dB is plotted up the ordinate axis. The figure of merit FOM_{DCF} expressed in ps/nm-dB is plotted along the abscissa axis. Curve CA corresponds to a chromatic dispersion of -150 ps/nm-km. Curve CB corresponds to a chromatic dispersion of -200 ps/nm-km.

10   Curve CC corresponds to a chromatic dispersion of -250 ps/nm-km. By their relatively shallow slope and their relatively large spacing, the curves CA, CB, CC show that in order to reduce the quality-to-price ratio criterion, and thus in order to improve it, it is more

15   effective to reduce the chromatic dispersion of the compensation optical fiber at constant figure of merit and it is counterproductive to increase the figure of merit of the compensation optical fiber at constant chromatic dispersion. However, to obtain a minimum

20   quality criterion, it is nevertheless necessary to increase the figure of merit beyond a certain threshold.

     Figure 7 is a diagram showing a family of curves plotting the variation in the quality criterion as a function of the figure of merit of the compensation

25   optical fiber at a chosen constant attenuation for the compensation optical fiber and in the case of compensating a standard single-mode line optical fiber. The quality criterion CQ expressed in dB is plotted up the ordinate axis. The figure of merit FOM_{DCF} expressed

30   in ps/nm-dB is plotted along the abscissa axis. Curve CA corresponds to a chromatic dispersion of 0.5 dB/km. Curve CB corresponds to a chromatic dispersion of 0.7 dB/km. Curve CC corresponds to a chromatic dispersion of 0.9 dB/km. By their relatively shallow

35   slope and their relatively large spacing, the curves CA, CB, CC show that in order to reduce the quality criterion, and thus to improve it, it is more effective

to increase the attenuation of the compensation optical fiber at constant figure of merit than it is to increase the figure of merit of the compensation optical fiber at constant attenuation. This is particularly true if the figure of merit is high and in particular greater than a value of approximately 200 ps/nm-dB. When compensating a non-zero dispersion shifted line optical fiber, the value of that preferred threshold is around 150 ps/nm-dB.

Figure 8 is a diagram showing a family of curves plotting the variation in the quality-to-price ratio criterion as a function of the figure of merit of the compensation optical fiber at a chosen constant attenuation for the compensation optical fiber and in the case of compensating a standard single-mode line optical fiber. The quality-to-price ratio criterion CQ2 expressed in dB is plotted up the ordinate axis. The figure of merit FOM_{DCF} expressed in ps/nm-dB is plotted along the abscissa axis. Curve CA corresponds to a chromatic dispersion of 0.5 dB/km. Curve CB corresponds to a chromatic dispersion of 0.7 dB/km. Curve CC corresponds to a chromatic dispersion of 0.9 dB/km. By the presence of a relatively flat minimum and their relatively large spacing, the curves CA, CB, CC show that in order to reduce the quality-to-price ratio criterion, and thus in order to improve it, it is more effective to increase the attenuation of the compensation optical fiber at constant figure of merit, and further there is an optimal range for the figure of merit of the compensation optical fiber, which must be neither too low nor too high. The optimum range is a function of attenuation but varies relatively little as a function of attenuation. A minimum figure of merit threshold must nevertheless be complied with in order to obtain a very good quality factor, but increasing the figure of merit as much as possible at any cost is not at all the method recommended by the invention.

Figure 9 is a diagram showing a family of curves

plotting the variation in the quality criterion as a
function of the chromatic dispersion of the compensation
optical fiber at a chosen constant figure of merit for
the compensation optical fiber and in the case of
5   compensating a standard single-mode line optical fiber.
The quality criterion CQ expressed in dB is plotted up
the ordinate axis. The chromatic dispersion expressed in
ps/nm-dB is plotted along the abscissa axis. Curve CA
corresponds to a figure of merit of 150 ps/nm-dB. Curve
10   CA corresponds to a figure of merit of 200 ps/nm-dB.
Curve CC corresponds to a chromatic dispersion of
250 ps/nm-dB. By their relatively steep slope and the
relatively small spacing between them, the curves CA, CB,
CC show that in order to reduce the quality criterion,
15   and thus in order to improve it, it is more effective to
reduce the chromatic dispersion of the compensation
optical fiber at constant figure of merit than it is to
increase the figure of merit of the compensation optical
fiber at constant chromatic dispersion. This is
20   particularly true if the figure of merit is high and in
particular greater than a value of approximately
200 ps/nm-dB. When compensating a non-zero dispersion
shifted line optical fiber the value of that preferred
threshold is around 150 ps/nm-dB.
25   Figure 10 is a diagram showing a family of curves
plotting the variation in the quality criterion as a
function of the attenuation of the compensation optical
fiber at a chosen constant figure of merit for the
compensation optical fiber and in the case of
30   compensating a standard single-mode line optical fiber.
The quality criterion CQ expressed in dB is plotted up
the ordinate axis. The attenuation expressed in dB/km is
plotted along the abscissa axis. Curve CA corresponds to
a figure of merit of 150 ps/nm-dB. Curve CA corresponds
35   to a figure of merit of 200 ps/nm-dB. Curve CC
corresponds to a chromatic dispersion of 250 ps/nm-dB.
By their relatively steep slope and their relatively

small spacing, the curves CA, CB, CC show that in order
to reduce the quality criterion, and thus in order to
improve it, it is more effective to increase the
attenuation of the compensation optical fiber at constant
5   figure of merit than it is to increase the figure of
merit of the compensation optical fiber at constant
attenuation. This is particularly true if the figure of
merit is high and in particular greater than a value of
approximately 200 ps/nm-dB. When compensating a non-zero
10   dispersion shifted line optical fiber the value of that
preferred threshold is around 150 ps/nm-dB.

       To obtain a simpler compensation module, the
compensation optical line preferably consists of a single
optical fiber connecting the input terminal to the output
15   terminal. At the cost of some complexity, a plurality of
compensation optical fibers in series provides better
compensation of the dispersion slope of the line optical
fiber.

       The signal amplification and chromatic dispersion
20   compensation system preferably comprises in succession a
first signal amplifier, a signal attenuator, a chromatic
dispersion compensation module of the invention, and a
second signal amplifier.

       The transmission line preferably comprises in
25   succession a single-mode line optical fiber adapted to
transmit information in a spectral domain of use and a
signal amplification and chromatic dispersion
compensation system of the invention.